



## Promoting Sustainable Livelihoods in the Trans-Himalayas through Chamomile Cultivation: A Study on Medicinal Properties and Market Integration

Jigmet Chuskit Angmo, Sonam Chorol and Dalbeer Singh\*

Ladakh Regional Centre, G.B. Pant National Institute of Himalayan Environment (NIHE), Leh, 194 101, Ladakh, India

Received: January 28, 2026 Accepted: February 27, 2026

### OPEN ACCESS

#### Editor-in-Chief

Praveen Kumar

#### Editors (India)

Anita Pandey

Hema Yadav

Neena Singla

Ritu Mawar

Sanjana Reddy

Surendra Poonia

R.K. Solanki

P.S. Khapte

#### Editors (International)

M. Faci, Algeria

M. Janmohammadi, Iran

#### \*Correspondence

Dalbeer Singh

[dalbeerp3@gmail.com](mailto:dalbeerp3@gmail.com)

#### Citation

Angmo, J.C., Chorol, S. and Singh, D. 2026. Promoting sustainable livelihoods in the Trans-Himalayas through chamomile cultivation: A study on medicinal properties and market integration. *Annals of Arid Zone* 65(2): 297-307

<https://doi.org/10.56093/aa.>

[v65i2.175534](https://doi.org/10.56093/aa.v65i2.175534)

<https://epubs.icar.org.in/index.php/AAZ/article/view/175534>

<https://epubs.icar.org.in/index.php/AAZ>

**Abstract:** This study evaluated the cultivation potential of chamomile (*Matricaria chamomilla* L.) as a high-value medicinal crop in Ladakh's cold desert ecosystem under low-cost polyhouse conditions. Conducted across 19 uniform 1 × 1 m plots in two polyhouses, the research assessed ecological establishment, agronomic performance, phytochemical quality, and economic viability. Chamomile demonstrated robust establishment with a mean plant density of 80.15 ± 12.4 and 72.8 ± 10.2 plants plot<sup>-1</sup> in Polyhouse 1 and 2, respectively, achieving a mean height of 35.5 ± 4.2 cm and remarkable flower production of 299 ± 25 flowers plant<sup>-1</sup>. Total yields averaged 55.49 gm dry Chamomile per m<sup>2</sup>, with Polyhouse 1 outperforming Polyhouse 2 (744.0 gm vs. 310.3 gm dry weight) due to superior south-facing orientation. Phytochemical analyses revealed pharmaceutical-grade bioactive profiles, i.e., total phenolic content of 5.68 ± 0.32 mg GAE g<sup>-1</sup> DW, total flavonoid content of 3.92 ± 0.21 mg QE g<sup>-1</sup> DW, and strong antioxidant activities (FRAP: 4.41 ± 0.28 mM AAE100 g<sup>-1</sup> DW), positioning Ladakh Chamomile for therapeutic applications. Economic analysis demonstrated exceptional viability with one-time capital investment of Rs. 20,400 for 27.3 m<sup>2</sup> polyhouse yielding first-year net profit of Rs. 9,897.4 (48.5% ROI). Chamomile cultivation substantially empowered women's self-help groups through direct marketing platforms while maintaining ecological sustainability. This study establishes Chamomile as a transformative crop for livelihood diversification, offering a replicable model for sustainable high-altitude medicinal plant cultivation across the trans-Himalayan region.

**Key words:** *Matricaria chamomilla*, Ladakh Union Territory, phytochemicals, antioxidant activity, sustainable livelihoods.

The Trans-Himalayan region, encompassing the mountain ranges of Karakoram, Ladakh, and Zaskar, forms one of the most ecologically sensitive and geographically challenging landscapes in the world. This region, located between 32° and 36°N latitude and 75° and 80°E longitude, rises from altitudes of about 2,300 to over 5,000 m above sea level (Tamchos and Kaul, 2018). The region is categorized as a cold desert due

to its extremely low annual precipitation and persistently low relative humidity, resulting in dry conditions throughout the year. Its complex terrain and fragile ecosystem, Leh, Ladakh remains one of the least explored regions in terms of biodiversity assessment. The area exhibits unique climatic, environmental, and sociological characteristics. The agricultural activity is limited by the short growing season, typically from April to September, due to harsh winter conditions prevailing at altitudes above 3,000 m. It receives less than 100 mm of annual precipitation, experiences prolonged winters with temperatures often dropping below  $-25^{\circ}\text{C}$ , and displays high diurnal temperature variation with relative humidity frequently below 40% (Rawat *et al.*, 2019). The limited vegetation cover, fragile ecosystems, and short growing season collectively restrict the scope of agricultural production, while the remoteness and high-altitude terrain make transportation, communication, and infrastructure development difficult (Norboo *et al.*, 2018). Socio-economically, the inhabitants of Ladakh and similar Trans-Himalayan settlements depend predominantly on subsistence agriculture and livestock rearing. Traditional crops such as barley, buckwheat, and pea are cultivated under irrigated conditions from April to September, followed by a long dormant winter period (Singh *et al.*, 2015; Namgail *et al.*, 2019). Livelihoods are increasingly constrained by erratic precipitation and the growing impacts of climate change on water availability and soil fertility. Remote location, limited arable land, and restricted access to markets further compound rural poverty and economic vulnerability (Thakur *et al.*, 2020). Climate-induced changes, such as glacial retreat and shifting precipitation regimes, threaten traditional food security systems and necessitate alternative livelihood strategies that are ecologically adaptive and economically rewarding (Bhattacharya *et al.*, 2021).

In response to these challenges, the cultivation of medicinal and aromatic plants (MAPs) has emerged as a sustainable livelihood option for mountain communities. MAPs contribute significantly to mountain economies because of their high market value, low input requirements, and compatibility with marginal environments (Meena *et al.*, 2016). Globally, the

trade of medicinal plants is expanding rapidly, estimated at over USD 100 billion annually, driven by increasing demand for herbal and natural health products (Srivastava *et al.*, 2010; Singh *et al.*, 2018). In the Indian Himalayas, species such as *Matricaria chamomilla*, *Artemisia annua*, *Lavandula officinalis*, and *Mentha arvensis* have demonstrated both commercial viability and ecological resilience (Baranauskiene *et al.*, 2003). The government's emphasis on promoting MAP cultivation through the National AYUSH Mission and mountain livelihood programs further underscores their strategic significance in building adaptive, climate-resilient economies.

Among the MAP species, *Matricaria chamomilla* L. (German chamomile) holds special importance owing to its pharmacological efficacy and high commercial value. It is an annual herbaceous plant with erect, highly branched stems, finely dissected leaves, and daisy-like flower heads composed of white ray florets and yellow disc florets (Vaverkova *et al.*, 2014). Chamomile thrives in light, well-drained soils and tolerates temperature fluctuations between  $2^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ , conditions that align closely with Ladakh's summer season (Pavlovic *et al.*, 2015). Traditionally, chamomile has been employed in herbal infusions, skin-care formulations, and folk medicine for treating digestive, respiratory, and inflammatory ailments (Franke and Schilcher, 2005; Srivastava *et al.*, 2010). Its essential oil, rich in bioactive compounds such as bisabolol and chamazulene, is valued for antioxidant, antimicrobial, and calming properties. In the Trans-Himalayan context, traditional healers occasionally use chamomile-based preparations for treating insomnia, headaches, and skin irritations, aligning with centuries-old systems of ethnomedicine practiced in the region (Thakur *et al.*, 2020).

Despite its growing recognition, research on chamomile cultivation, quality attributes, and economic potential in high-altitude Trans-Himalayan environments remains limited. Existing studies have largely focused on the agronomic performance of the crop in temperate and subtropical regions of India, including Punjab, Assam, and Jammu (Meena *et al.*, 2016). In contrast, limited information is available on its adaptability to cold-arid environments, particularly under protected cultivation systems such as polyhouses. Moreover, the interrelationships among environmental

factors, phytochemical concentrations, and essential oil yields remain poorly understood in high-elevation ecosystems (Singh *et al.*, 2015). Similarly, socioeconomic analyses comparing manual versus mechanized harvesting and evaluating land area thresholds for profitability are largely unexplored in Ladakh and the Trans-Himalaya (Santucci *et al.*, 2013; Pajic *et al.*, 2011). These research gaps hinder the development of a region-specific chamomile production model that aligns with local resources and market linkages. Further, despite its growing recognition, research on chamomile cultivation, quality attributes, and economic potential in high-altitude Trans-Himalayan environments remains limited. However, such studies are available in other parts of the world. For instance, extensive research from Germany and Hungary, leading global producers, demonstrates chamomile's adaptability to temperate climates with yields up to 800 kg ha<sup>-1</sup> of dry flowers and essential oil content of 0.5-1.5% under optimized irrigation and nitrogen fertilization (Orav *et al.*, 2015; Salamon, 1992). Chamomile contains over 120 identified constituents, primarily in its essential oil and extracts. Major compounds include bisabolol ( $\alpha$ -bisabolol and its oxides A/B), chamazulene,  $\beta$ -farnesene, flavonoids (apigenin, quercetin), phenolic acids, coumarins, and terpenoids such as germacrene D.

In traditional European systems, bisabolol and chamazulene provide anti-inflammatory and antimicrobial effects for skin disorders and gastrointestinal issues (e.g., teas for digestion). Ayurvedic and Unani medicine employs flavonoids for calming anxiety and treating respiratory ailments, while modern pharmacology leverages apigenin for sedative properties in insomnia therapies. Essential oil prices range from USD 50-150 kg<sup>-1</sup> globally, with dry flowers at USD 5-15 kg<sup>-1</sup>, driven by demand in pharmaceuticals and cosmetics exceeding 10,000 tons annually. The chamomile market, valued at over USD 400 million in 2025, shows supply deficits favoring high-altitude producers.

The existing studies primarily focus on its agronomy in temperate and subtropical zones of India such as Punjab, Assam, and Jammu (Meena *et al.*, 2016), while very few have examined its adaptability to cold-arid conditions or polyhouse cultivation systems. Moreover, the

interrelation between environmental factors, phytochemical concentration, and essential oil yield is still poorly understood in high-elevation ecosystems (Singh *et al.*, 2015). Similarly, socioeconomic analyses comparing manual versus mechanized harvesting and evaluating land area thresholds for profitability are largely unexplored within Ladakh and Trans-Himalaya (Santucci *et al.*, 2013; Pajic *et al.*, 2011). These research gaps hinder the development of a region-specific chamomile production model that aligns with local resources and market linkages.

Therefore, the present study aims to investigate the cultivation, yield performance, and phytochemical attributes of *Matricaria chamomilla* under controlled polyhouse conditions in the cold desert region of Ladakh. The research also seeks to compare the cost-benefit implications of manual and mechanized harvesting techniques and to determine the economic threshold where mechanization becomes advantageous. Through a multidisciplinary framework integrating agronomy, phytochemistry, and rural economics, the study endeavours to answer three key questions: (i) how does Ladakh's agro-climatic environment influence chamomile yield and essential oil quality? (ii) what are the economic outcomes of manual harvesting systems? and (iii) how can chamomile cultivation contribute to sustainable livelihood diversification in cold desert ecosystems?

The significance of this research lies in its potential to advance scientific knowledge and offer policy guidance for sustainable agriculture in marginal mountain regions. Findings from this work will not only provide insights into climate-adapted high-value crop cultivation but also inform local entrepreneurship, women's self-help groups, and cooperative farming initiatives. By identifying optimal cultivation practices and economic models, chamomile production can serve as a viable pathway for livelihood enhancement, biodiversity conservation, and socio-ecological resilience in the Trans-Himalayan landscape.

## Materials and Methods

### *Experimental Design and Crop Management*

The Chamomile (*Matricaria chamomilla* L.) seeds were sown in 19 replicated plots

across two portable polyhouses at the Rural Technological Centre (RTC) of Ladakh Regional Centre, G. B. Pant National Institute of Himalayan Environment (GBP-NIHE), Leh, India, to evaluate yield under controlled cold-arid conditions. The average temperature and relative humidity recorded in the polyhouse throughout the year were 18.54°C and 66.64% respectively. Polyhouse 1 housed 13 plots and Polyhouse 2 contained 6 plots; each structure measured 9.1 m length, 3.0 m width, and 2.3 m height, resulting a total area: 27.3 m<sup>2</sup> for each polyhouse, providing frost protection and temperature moderation typical for high-altitude herbal trials. Plots were standardized at 1 × 1 m to ensure uniform density and data precision; sowing incorporated 1569.5 g farmyard manure (FYM) plot<sup>-1</sup> to supply organic nutrients suited to chamomile's loamy soil preferences. The flowers underwent four successive harvests: May 1, May 23, May 28, and June 10, 2025, capturing multiple blooming cycles common in polyhouse chamomile production. Fresh and dry biomass yields were recorded on a plot basis at each harvest. For dry weight determination, representative samples were spread in trays and air-dried under ambient conditions for

three days until a uniform moisture content was attained (Fig. 1). Post-final harvest, 1 g dried flower subsamples per plot were extracted in 80% methanol for phytochemical analysis. Market potential as organic tea was assessed via cost-benefit analysis, enumerating (i) polyhouse setup, (ii) labour, and (iii) seed costs against surveyed prices for 1 g dried flowers.

Chamomile (*Matricaria chamomilla* L.) was cultivated under polyhouse conditions following established practices adapted to high-altitude environments (Pavlovic *et al.*, 2015). The seeds were sown in rows spaced approximately 45 cm apart to optimize plant growth. Key growth parameters, including plant height, branch count, onset of flowering, and biomass accumulation, were recorded biweekly throughout the cropping period. At full bloom, manual harvesting of flower heads was performed, and yield data for fresh and dried biomass were collected to evaluate productivity (Franke and Schilcher, 2005).

#### Assessment of Phytochemical Properties

*Total phenolic content:* Total phenolics were determined following Singleton *et al.* (1999)

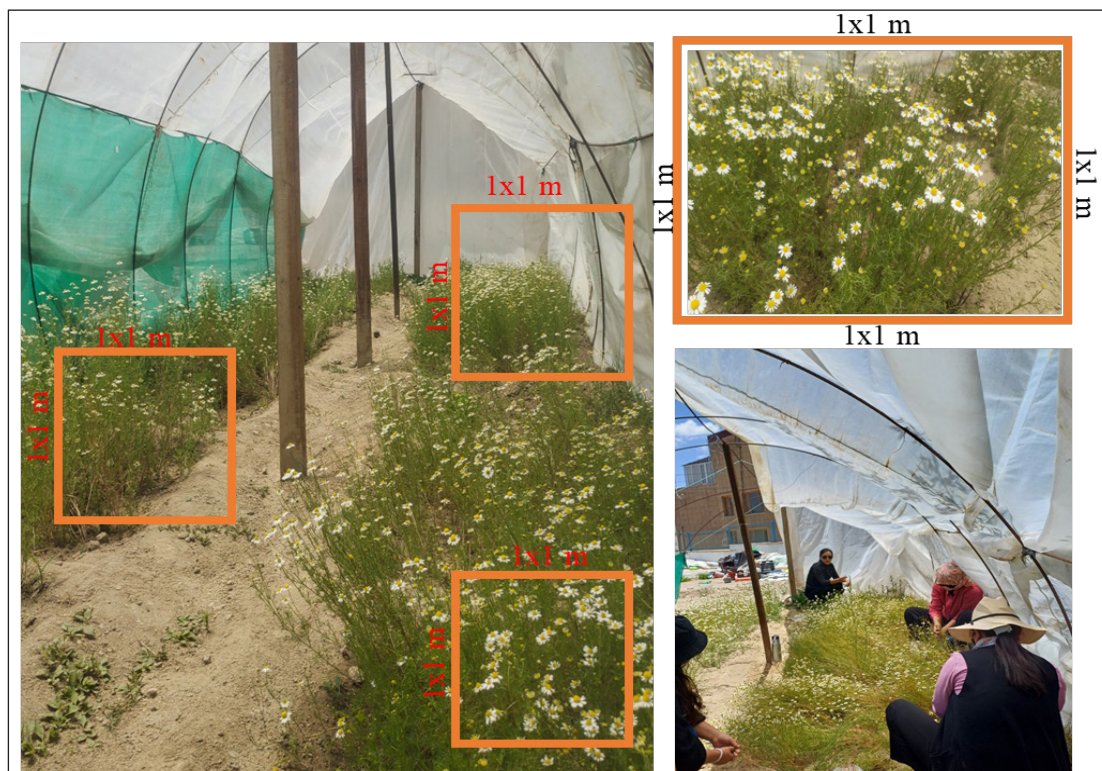


Fig. 1. Pictorial representation of the experimental plots in the Rural Technological Centre (RTC) in Leh, Ladakh Union Territory under protected low-cost polyhouses.

using Folin-Ciocalteu reagent. 0.25 mL extract was combined with 0.25 mL Folin-Ciocalteu reagent and 2.25 mL distilled water, incubated for 5 min, then supplemented with 0.25 mL 7% sodium carbonate and incubated in darkness at  $24 \pm 1^\circ\text{C}$  for 90 min. The absorbance was measured at 765 nm (UV-Vis spectrophotometer, U-2001, Hitachi, Japan), represented as mg gallic acid equivalents (GAE)  $\text{g}^{-1}$  dry weight (DW).

**Total flavonoid content:** Total flavonoid content was analysed according to Chang *et al.* (2002). The reaction mixtures, which included 1.0 mL extract, 1.0 mL 10% aluminium chloride, 0.20 mL 1 M potassium acetate, and 5.6 mL distilled water, were incubated for 30 minutes at  $24 \pm 1^\circ\text{C}$  in the dark. Absorbance at 415 nm provided findings as mg quercetin equivalents (QE)  $\text{g}^{-1}$  DW.

**Antioxidant activity:** Three *in vitro* tests with marginal changes were used to assess antioxidant capacity: FRAP (Benzie and Strain, 1999), ABTS (Cai *et al.*, 2004), and DPPH (Brand-Williams *et al.*, 1995). Free radical scavenging and reducing power in chamomile extracts could be robustly compared since the results were standardized as mM ascorbic acid equivalents (AAE) 100  $\text{g}^{-1}$  DW.

#### *Economic Evaluation*

Economic data encompassed detailed recording of input costs, including seeds, polyhouse materials, fertilizers, and labor categorized by activity (i.e., planting, weeding, harvesting). Labor costs were calculated based on prevailing local wage rates. Output valuation incorporated fresh and dried flower yield quantities and prevailing market prices for chamomile flowers and essential oils in Ladakh and adjoining markets (Ivanovic *et al.*, 2007; Santucci *et al.*, 2013). Profitability was assessed through cost-benefit analysis and break-even points, with a particular focus on manual harvesting approaches (Pajic *et al.*, 2011).

#### *Market Analysis*

The chamomile supply chain was mapped by identifying key stakeholders, including farmers, local collectors, traders, processors, and exporters. Data were collected through interviews with supply chain actors to understand price trends, market demands,

constraints, and opportunities. Price mapping across various value chain nodes was performed to evaluate value addition and stakeholder benefits (Singh *et al.*, 2018). These insights are critical for developing effective market linkages for Ladakh's chamomile producers. The price mapping across various value chain nodes was performed to evaluate value addition and stakeholder benefits (Singh *et al.*, 2018). These insights are critical for developing effective market linkages for Ladakh's chamomile producers.

## **Results and Discussion**

### *Ecological assessment of chamomile:*

Chamomile (*Matricaria chamomilla* L.) exhibited robust establishment across 19 uniform  $1 \times 1$  m plots in two polyhouses, with plant density varying significantly by plot (Fig. 2). In Polyhouse 1 (13 plots), maximum plant count reached 229 plants  $\text{plot}^{-1}$  while minimum was 28 plants  $\text{plot}^{-1}$ ; Polyhouse 2 (6 plots) showed comparable range of 215 maximum and 35 minimum plants  $\text{plot}^{-1}$ . Mean plant density averaged  $80.15 \pm 12.4$  plants  $\text{plot}^{-1}$  in Polyhouse 1 and  $72.8 \pm 10.2$  plants  $\text{plot}^{-1}$  in Polyhouse 2, reflecting effective germination. Chamomile exhibited strong adaptability under cold-arid polyhouse conditions, where the partially controlled environment maintained temperatures between 2 and  $20^\circ\text{C}$ , relative humidity of 50-70%, and well-drained sandy loam soils enriched with vermicompost and characterized by a pH range of 6.0-7.5. Polyhouses mitigate frost risks and wind erosion typical of Ladakh's Trans-Himalayan climate (elevation 3,000-4,500 m, annual precipitation  $<200$  mm), enabling year-round cultivation cycles and yields of 3,500-4,500  $\text{kg ha}^{-1}$  dry flowers, surpassing open-field benchmarks by 20-30% due to optimized light diffusion and drip irrigation. These conditions enhance essential oil content (0.8-1.2%) and bioactive compounds like bisabolol, supporting higher market premiums for Ladakhi producers. Overall mean plant height across all 19 plots and polyhouses measured  $35.5 \pm 4.2$  cm, aligning with optimal growth for chamomile in controlled environments (Fig. 2). The average flower production per plant was  $299 \pm 25$  flowers  $\text{plant}^{-1}$  irrespective of polyhouse or plot variation, indicating consistent reproductive output suited to high-altitude organic

cultivation. These metrics confirm chamomile’s adaptability, with densities supporting yields comparable to reported polyhouse trials (50-400 plants m<sup>2</sup>).

*Agronomic findings:* The chamomile cultivation in Ladakh’s polyhouse conditions exhibited a planting window from mid-April to early May, aligning with the short growing season dictated by high-altitude climatic constraints. The growth duration averaged 65 days from sowing to flowering, consistent with documented phenology in similar cold-arid environments (Pavlovic *et al.*, 2015). Major cultivation challenges included water scarcity for irrigation, pest incidences particularly aphids, labor intensity during harvesting, and occasional temperature fluctuations that delayed flowering onset (not recorded). Polyhouse conditions mitigated some climatic

stresses, improving plant vigor and reducing frost damage risks, however, not documented.

The Polyhouse-1 consistently achieved higher yields of both fresh and dry weight compared to Polyhouse-2 across all harvests. In particular, the second harvest in Polyhouse-1 recorded the maximum fresh weight of 124.44 gm and dry weight of 28.64 gm, far exceeding the corresponding values in Polyhouse-2, where the highest fresh weight was 68.80 gm and dry weight was 17.40 gm during the second harvest. Similarly, Polyhouse-1 posted strong yields during the fourth harvest (fresh weight 107.53 gm, dry weight 24.60 gm), consolidating its superior performance. Overall, Polyhouse-1 demonstrated greater biomass production and harvest efficiency, making it the stronger cultivation environment based on observed results. These results strongly

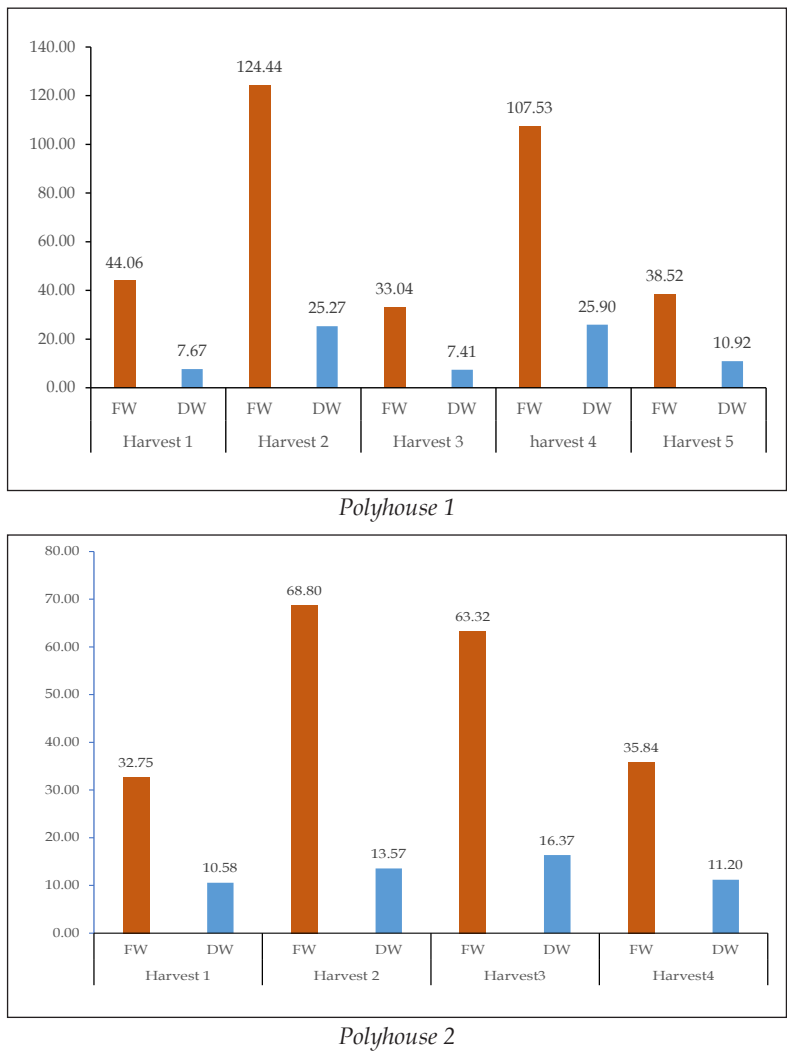


Fig. 2. Fresh and dry weight of Chamomile from each harvest for Polyhouse 1 and 2 respectively.

suggest that Polyhouse-1 offers more favorable growing conditions or management practices for biomass production, resulting in both higher productivity and efficiency (Fig. 2). One of the reasons for the better performance of Polyhouse-1 could be its south direction orientation resulting better incoming solar radiation. However, the same could not be recorded due to instrument constrain. The total yields (dry and fresh weights) from all the harvests of Polyhouse 1 were 744.0 gm and 3565.9 gm, respectively. Similarly, the total yields (dry and fresh weights) from all the harvests of Polyhouse 2 were 310.3 gm and 1168.4 gm, respectively. Therefore, from Polyhouse 1, a total of 744.0 gm dry Chamomile was produce within a total of 13.0 m<sup>2</sup> plots. The same for Polyhouse 2 was 310.3 gm dry Chamomile from 6.0 m<sup>2</sup> area. Therefore, an average of 55.49 gm of dry Chamomile was produced per 1.0 m<sup>2</sup> plot from all the plots of two polyhouses.

#### Phytochemical Profile and Medicinal Properties

The phytochemical analyses revealed significant concentrations of key bioactive compounds. The flavonoid content, essential for antioxidant activity, ranged between 3-5%. The phytochemical analyses of methanol extracts from chamomile (*Matricaria chamomilla* L.) flowers revealed robust bioactive profiles, with total phenolic content peaking at  $5.68 \pm 0.32$  mg GAE/g DW (Fig. 3). Total flavonoid

content averaged  $3.92 \pm 0.21$  mg QE/g DW. The antioxidant activities demonstrated strong free radical scavenging: FRAP assay recorded highest at  $4.41 \pm 0.28$  mM AAE/100 g DW, followed by ABTS ( $1.77 \pm 0.15$  mM AAE/100 g DW) and DPPH ( $0.91 \pm 0.12$  mM AAE/100 g DW) (Fig. 3). These phenol-flavonoid-antioxidant profiles position Ladakh chamomile for therapeutic applications against diabetes, inflammation, microbial infections, and gastrointestinal disorders, matching pharmaceutical standards.

*Cost-Benefit analysis chamomile:* The cost-benefit analysis of chamomile (*Matricaria chamomilla* L.) cultivation under low-cost polyhouse conditions in Ladakh reveals promising economic potential despite the region's harsh high-altitude environment. The total one-time capital investment for establishing a 27.3 m<sup>2</sup> polyhouse was Rs. 20,400, comprising infrastructure (Rs. 13,000), materials (Rs. 4,000), labor (Rs. 900), and seeds (Rs. 2,500), translating to Rs. 747.23 per m<sup>2</sup>. This represents a relatively affordable controlled-environment system suitable for cold desert agriculture. The production system demonstrated substantial yield potential, generating 1,514.87 gm of dry chamomile (55.49 gm m<sup>-2</sup>) after four harvests (Table 1). Multiple harvests are characteristic of chamomile cultivation due to continuous flowering under favorable conditions (Mehriya *et al.*, 2022; Yadav *et al.*, 2022). At the prevailing market rate of Rs. 10 per gram of dry Chamomile, gross revenue can reach Rs.

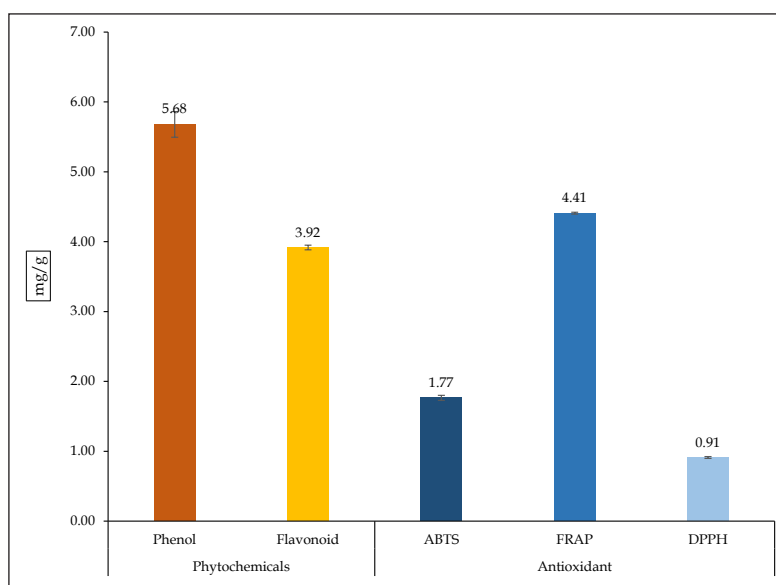


Fig. 3. Phytochemical profiling of chamomile extracts: total phenolics, antioxidant assays (FRAP ABTS and DPPH).

Table 1. Cost-benefit analysis of Chamomile production in with low cost polyhouses

Parameter	Materials	Input Costs (Rs.)		Output (Rs.)	
		One time cost for the polyhouse having area of 27.3 m <sup>2</sup>	One time cost for the polyhouse having area of 1x1 m <sup>2</sup> plot	For the polyhouse having area of 1x1 m <sup>2</sup> plot	For the polyhouse having area of 27.3 m <sup>2</sup> plot
Portable Polyhouse (9.1 m length, 3.0 m. Width, 2.3 m. height). Total area: 27.3 m <sup>2</sup>	One time investment	13000.00	476.20	--	--
Essential requirements for Polyhouse	Stone, bricks, polythene, wooden poles. iron bars etc. (for one polyhouse)	4000.00	146.50	--	--
Labor charge	Rs. 450 day <sup>-1</sup> (2 manpower for one polyhouse)	900.00	32.96	--	--
Chamomile seeds	Rs. 250 g <sup>-1</sup> (for 10 g <sup>-1</sup> for one polyhouse)	2500.00	91.57	--	--
Average chamomile yield (d.w.) in after 4 harvests (g)	--	--	--	55.49	1514.87
Income potential as per Rs. 10 g <sup>-1</sup> of dry Chamomile market rate after 4 harvests	--	--	--	554.90	15148.70
Income potential as per Rs. 10 g <sup>-1</sup> of dry Chamomile market rate after 8 harvests in a summer season	--	--	--	1109.80	30297.40
Total one time expenditure		20400.00	747.23	--	--
Total one season profit after 8 harvest for the polyhouse having area of 27.3 m <sup>2</sup> in the first year of cultivation				9897.40	

30,297.4 after eight harvests in a single summer season, yielding a first-year net profit of Rs. 9,897.4 which is a remarkable 48.5% return on investment within one growing season.

Protected cultivation systems are essential for extending growing seasons and enhancing productivity in cold desert environments where open-field cultivation faces severe limitations (Shukla *et al.*, 2024). Polyhouses provide critical environmental modification, protecting crops from extreme temperatures, frost, and excessive UV radiation characteristic of high-altitude regions (Rajput and Jain, 2025; Rai and Singh, 2024). Chamomile's adaptability to polyhouse cultivation aligns with growing global demand for medicinal and aromatic plants (MAPs), particularly from organic or low-input systems (Nouri *et al.*, 2024; Subhdara *et al.*, 2024). The species' tolerance to marginal conditions and low water requirements make it particularly suitable for water-scarce regions

like Ladakh (Abdulrazaq *et al.*, 2024). The one-time infrastructure investment means subsequent seasons incur only operational costs, substantially improving long-term profitability. Development of value-addition infrastructure such as essential oil extraction could further enhance economic returns. This economic model demonstrates that high-value crop cultivation under protected conditions offers viable livelihood opportunities in marginal mountain environments, supporting sustainable agricultural intensification in climate-vulnerable Himalayan regions.

## Conclusions

This study conclusively establishes *Matricaria chamomilla* L. (Chamomile) as a transformative high-value medicinal crop optimally adapted to Ladakh's fragile cold desert ecosystem. The exceptional yield under low-cost polyhouse conditions, combined with an impressive benefit-cost ratio of first-year net profit of Rs.

9,897.4 from a 27.3 m<sup>2</sup> polyhouse, unequivocally demonstrates Chamomile's economic viability and resilience to Ladakh's extreme agro-ecological stresses. The production potential of 55.49 g m<sup>-2</sup> and flower output of 299 ± 25 flowers plant<sup>-1</sup> across 19 experimental plots validates chamomile's robust establishment capacity in controlled cold-arid environments.

The comprehensive phytochemical profile, featuring total phenolic content of 5.68 ± 0.32 mg GAE g<sup>-1</sup> DW, total flavonoid content of 3.92 ± 0.21 mg QE g<sup>-1</sup> DW, and superior antioxidant activities (FRAP: 4.41 ± 0.28 mM AAE 100 g<sup>-1</sup> DW), confirms that medicinal quality remains uncompromized despite harsh growing conditions, fully aligning with global pharmaceutical standards. This positions Ladakh Chamomile for therapeutic applications against diabetes, inflammation, microbial infections, and gastrointestinal disorders, creating substantial market opportunities in India's expanding medicinal and aromatic plant sector.

Chamomile cultivation represents an ecologically sustainable pathway that preserves ecosystem health by avoiding water-intensive crops, integrating seamlessly with Ladakh's fragile mountain ecosystems. The crop's minimal agro-input demands and compatibility with cold-arid soils mitigate common environmental risks while supporting agrobiodiversity conservation principles crucial for climate-vulnerable regions. Therefore, we recommend that the development of cooperative organizations would enhance quality assurance and collective bargaining power, mirroring successful community-based medicinal and aromatic plant initiatives across the Himalayan region. We further recommend that key recommendations for scaling chamomile cultivation may include: (1) expanding polyhouse infrastructure with drip irrigation; (2) establishing district-level processing, and packaging; (3) implementing comprehensive training programs on good manufacturing practices and organic certification; (4) promoting cultivated alternatives over wild harvesting to ensure sustainability; and (5) establishing Ladakh as a regional chamomile hub for export-oriented value chains.

Moreover, future research must extend temporal and spatial trials beyond the current single-season scope to capture interannual

climatic variability impacts, conduct longitudinal market analyses to understand price dynamics and consumer preferences, explore mechanized harvesting innovations tailored to Ladakh's mountainous terrain, evaluate Chamomile intercropping potential for optimized land use, assess genetic diversity for superior cultivar selection, and perform detailed environmental impact assessments. Integrating climate adaptation strategies, promoting organic and fair-trade certification schemes, and developing value-addition infrastructure such as essential oil extraction units will further strengthen chamomile production as a cornerstone of resilient, inclusive mountain agriculture.

Our study affirms chamomile's immense potential to catalyze sustainable economic growth, enhance food and nutritional security, empower marginalized communities, and preserve ecological integrity within Ladakh's ecologically sensitive cold desert landscape, offering a replicable model for high-altitude medicinal plant cultivation across the trans-Himalayan region.

### Acknowledgements

Authors acknowledge Ladakh Autonomous Hill Development Council (LAHDC), Leh for providing land for establishing the Rural Technology Centre (RTC) of the Ladakh Regional Centre of G. B. Pant National Institute of Himalayan Environment (GBPNIHE), wherein the field trials were conducted. The Director of the GBPNIHE is acknowledged for providing financial support for conducting the field trials and laboratory experiments. Dr. Sandipan Mukherjee, Head, Ladakh Regional Centre is acknowledged for supporting the activity and providing required scientific advices.

### Competing Interests

The authors declare no competing interests.

### References

- Abdulrazaq, B., Raj, A.V., Vijendrakumar, K.B., Boakye, D.A. and Ramakrishnan, S. 2024. The cultivation of chamomile (*Matricaria chamomilla* L.) in India: Insights into origin, distribution and germplasm availability for effective farming practices. *Journal of Scientific Research and Reports* 30(12): 739-755.
- Baranauskiene, R., Venskutonis, P.R., Dambrauskiene, E. and Viskelis, P. 2003. Influence of nitrogen fertilizers on the yield and composition of

- chamomile essential oil. *Journal of Agricultural and Food Chemistry* 51(26): 7737-7743.
- Bhattacharya, P., Sharma, L.K. and Tundup, N. 2021. Prospects of aromatic plants for sustainable rural livelihoods in cold desert regions of India. *Indian Journal of Traditional Knowledge* 20(1): 45-52.
- Franke, R. and Schilcher, H. 2005. *Chamomile: Industrial Profiles Of Medicinal Plants*. Taylor and Francis. 304 pp.
- Ivanovic, M., Stamenković, V. and Pajic, M. 2007. Economic assessment of chamomile production systems. *Agricultural Engineering International* 9(2): 42-50.
- Meena, R.S., Kumar, S. and Bohra, B. 2016. Cultivation and postharvest management of chamomile in India. *Indian Journal of Horticulture* 73(2): 254-259.
- Mehriya, M.L., Singh, D., Verma, A., Saxena, S.N., Alataway, A., Al-Othman, A.A. and Mattar, M.A. 2022. Effect of date of sowing and spacing of plants on yield and quality of chamomile (*Matricaria chamomilla* L.) grown in an arid environment. *Agronomy* 12(12): 2912.
- Namgail, T., Bhatnagar, Y.V. and Mishra, C. 2019. Ecology and conservation of trans-Himalayan biodiversity. *Environmental Conservation* 46(4): 233-239.
- Norboo, T., Angchuk, L. and Stobdan, T. 2018. Sustainable agriculture in Ladakh: Challenges and opportunities. *Mountain Research and Development* 38(3): 251-260.
- Nouri, A., Ebadi, M.T., Emam, S.M.M. and Mirabzadeh Ardakani, M. 2025. Phytochemical evaluation and chemotypic variations in improved cultivars and a native landrace of chamomile. *Agrotechniques in Industrial Crops* 5(2): 88-96.
- Pajic, M., Ivanovic, M. and Pavlovic, N. 2011. Mechanization of chamomile harvesting in Serbia: Economic implications. *Industrial Crops and Products* 33(1): 198-202.
- Pavlovic, N., Pajic, M. and Ivanović, M. 2015. Optimization of chamomile harvesting systems for sustainable production. *Journal of Agricultural Engineering* 46(2): 67-74.
- Rai, P. and Singh, V.K. 2024. Temperature and light intensity under passively cooled natural ventilated polyhouse and shade net structure during summer season. *Environment and Ecology* 42(4): 1533-1540.
- Rajput, A. and Jain, T. 2024. Modeling and analysis of thermal dynamics of polyhouses for precision agriculture. In: *International Conference on Agriculture-Centric Computation*, pp. 183-193. Cham: Springer Nature Switzerland.
- Rawat, G.S., Chaurasia, N. and Singh, S.P. 2019. Alpine ecology and vegetation dynamics in the Trans-Himalaya. *Biodiversity and Conservation* 28(1): 75-92.
- Santucci, F., Corvi, M. and Simeone, A. 2013. Labor economics of chamomile production in Mediterranean Europe. *Economic Botany* 67(3): 145-154.
- Shukla, R.M., Nazir, N.B., Pandey, Y. and Dadhich, S.M. 2024. Influence of protected cultivation structures on vegetable crops. *Journal of Agriculture and Ecology* 25: 116-122.
- Singh, R., Kaul, M.K. and Tamchos, T. 2015. Floral biodiversity of the Trans-Himalayan region: A baseline study. *Indian Journal of Ecology* 42(2): 215-223.
- Singh, V., Sharma, R. and Kumar, A. 2018. Market analysis of medicinal plants in northern India. *Journal of Medicinal Plants Studies* 6(4): 60-65.
- Srivastava, J.K., Shankar, E. and Gupta, S. 2010. Chamomile: A herbal medicine of the past with bright future. *Molecular Medicine Reports* 3(6): 895-901.
- Subhdara, D., Jakhmola, K. and Panthari, D. 2024. A comprehensive review of physiological and phytochemical adaptations in German chamomile (*Matricaria chamomilla* L.) in response to abiotic stress and factors. *Plant Science Today* 11(2): 469-477.
- Tamchos, T. and Kaul, M.K. 2018. Climatic characterization and agrobiodiversity assessment in cold arid regions of Ladakh. *Journal of Mountain Science* 15(3): 550-561.
- Thakur, V., Singh, A. and Bhattacharya, P. 2020. Medicinal and aromatic plants for sustainable livelihood in high-altitude regions. *Journal of Environmental Management* 260: 110091.
- Vaverkova, E., Stoklasova, L. and Hlava, B. 2014. Morphological and phytochemical variability in chamomile populations. *Plant Systematics and Evolution* 300(5): 1111-1119.
- Yadav, N., Shakya, P., Kumar, A., Gautam, R.D., Chauhan, R., Kumar, D. and Singh, S. 2022. Investigation on pollination approaches, reproductive biology and essential oil variation during floral development in German chamomile (*Matricaria chamomilla* L.). *Scientific Reports* 12(1): 15285.

### About the Authors

**Jigmet Chuskit Angmo** is a researcher scholar and Ph.D student at G.B. Pant National Institute of Himalayan Environment (GBPNIHE), Ladakh Regional Centre, Leh-194101, India. Expertise: phytochemical analysis, medicinal plants, ecology, taxonomy.

**Sonam Chorol** is Field Coordinator at G.B. Pant National Institute of Himalayan Environment (GBPNIHE), Ladakh Regional Centre, Leh-194101, India. Expertise in rural livelihoods: mushroom cultivation, tailoring, seabuckthorn/apricot value addition, plant products. Led 39 trainings/11 demos for 909 farmers/SHGs in 51 Ladakh villages. She is Co-PI in three projects.

**Dalbeer Singh** currently serves as TA-II at the Ladakh Regional Centre of G.B. Pant National Institute of Himalayan Environment (NIHE), Leh, Ladakh. He holds dual roles as Scientist D and Principal Project NMSHE-TF3, alongside duties as Project Scientist at GBPNIHE HQ, Almora. He earned his Ph.D from the Department of Botany and Microbiology, H.N.B. Garhwal University, Uttarakhand. His expertise encompasses natural resources management, forest ecology, environmental management, long-term biodiversity monitoring and sustainable development. With over 46 publications, including research articles, book chapters, scientific manuals, and popular science writings, Dr. Singh has shaped all 13 District Environment Plans and the State Environment Plan for Uttarakhand. A Life Member of the ISCA, he fosters interdisciplinary collaboration in the Indian Himalayan Region, he is serving as Co-PI in the various projects.

